

Statistical Properties of Solar Granulation from the SOUP Instrument on Spacelab 2

K. Topka, A. Title, T. Tarbell, S. Ferguson, R. Shine (Lockheed PARL),

Abstract

The Solar Optical Universal Polarimeter (SOUP) on Spacelab 2 collected movies of solar granulation completely free from atmospheric blurring, and are not degraded by pointing jitter (the pointing stability was $0.003''$ root mean square). The movies illustrate that the solar five minute oscillation has a major role in the appearance of solar granulation and that exploding granules are a common feature of the granule evolution. Using 3-D Fourier filtering techniques we have been able to remove the oscillations and demonstrate that the autocorrelation lifetime of granulation is a factor of two greater in magnetic field regions than in field-free quiet sun. We have been able to measure horizontal velocities and observe flow patterns on the scale of meso- and supergranulation. In quiet regions the mean flow velocity is 370 m/s while in magnetic regions it is about 125 m/s. We have also found that the root mean square (rms) fluctuating horizontal velocity field is substantially greater in quiet sun than in strong magnetic field regions. By superimposing the location of exploding granules on the average flow maps we find that they appear almost exclusively in the center of mesogranulation size flow cells. Because of the non-uniformity of the distribution of exploding granules, the evolution of the granulation pattern in mesogranule cell centers and boundaries differs fundamentally. It is clear from this study there is neither a typical granule nor a typical granule evolution.

ANALYSIS and SUMMARY

The continuum intensity pattern of the solar photosphere is due to granulation (convective overshoot and turbulent flows), p- and f-mode oscillations, local internal gravity waves, and magnetic fields. From a single photograph it is impossible to separate these phenomenon. With the SOUP time sequences of images and 3-D Fourier filtering most of the effects of global oscillations, and some of the effects of waves, can be separated from the intensity pattern due to granulation. Simultaneous magnetograms have allowed us to isolate some of the effects of magnetic fields as well, and many of these results are presented here.

- On average granules are brighter in magnetic field areas than in quiet sun and the magnitude of the intensity increase is nearly independent of field strength until pores

form. Temporal intensity fluctuations are a maximum for quiet sun and decrease as magnetic flux in the local neighborhood increases. The fluctuations decrease monotonically with increasing field strength until pores form. The effects of magnetic fields on granulation extend well beyond (perhaps $2'' - 4''$ or more) the boundaries of the individual magnetic flux tubes.

- The quasi steady component of the horizontal velocities of granules averages 370 m/s (with 4 arc second mask size) in quiet sun. The patterns in this flow are on the scale of meso- and supergranules. Magnetic fields strongly inhibit the average horizontal flow speeds of granules, to 275 m/s for weak fields, and to 100 m/s for strong fields.
- Attempts to directly measure the motion of individual granules by tracking the location of their centers during their lifetimes yields an average of about 1.0 km/sec. The shortest lived granules move some 30% - 40% faster than the longer lived ones.
- Measurements of the rms fluctuating horizontal velocities are strongly dependent on the type of solar region and the size of the aperture used for correlation tracking. In quiet sun these velocities go from about 0.45 to 1.4 km/s and in strong magnetic regions the increase is from 0.3 to 0.75 km/s as the measurement aperture decreases from 4 to 1 arc seconds. The velocities measured by the smallest apertures are on the order of velocities required for models of solar line widths. The rms velocities are lower in magnetic field areas by about 45%.
- Exploding granules tend to occur inside of mesogranules - in regions of positive divergence of the horizontal flow. Every 900 seconds, on average, all of the area within these cells has been affected at least once by the expansion fronts of an exploding granule. This also means that granules located within the network between mesogranules have a much different evolutionary history than those within the cells.

FIGURE CAPTIONS

Fig 1. SOUP Granulation Image. Quiet sun region. Contours reveal magnetic areas and are from a simultaneous Big Bear Solar Observatory magnetogram.

Fig 2. SOUP Granulation Image. Active region with pores. Superimposed are magnetic field strength contours.

Fig 3. Mean Intensity Image. Mean intensity image of the pore region is formed by averaging all 166 frames (28 minutes) of the sequence. On average the continuum appears brighter inside the magnetic areas.

Fig 4. Mean Intensity vs. Magnetic Field. The mean continuum intensity outside of magnetic areas is normalized to 100. On average the mean intensity inside magnetic areas is greater than that outside, and is nearly independent of field strength between 0 and -275 G. After this the mean intensity drops quickly because pores form.

Fig 5. RMS Map. The root-mean-square (RMS, black=small RMS, white=large RMS) of the continuum intensity during the observing period for the pore region (fig. 2). Magnetic contours are shown superimposed.

Fig 6. RMS vs. Magnetic Field. The mean RMS in intensity is plotted versus magnetic field strength for the pore region shown in figure 2. Solid - raw data, dashed - filtered to remove 5-minute oscillations. The diamonds plotted at 0 Gauss are the mean RMS intensity from the quiet sun sequence (fig. 1). The magnetic field suppresses the continuum intensity RMS until pores start to form at -275 G.

Fig 7. Horizontal Flow Speeds. Measured from local correlation tracking in both the quiet sun (fig. 1) and pore regions (fig 2).

Fig 8. Flow Speed vs. Magnetic Field. Scatter plot showing flow speed versus magnetic field strength. The solid line shows the mean flow speed. The mean speed in the quiet sun region is also plotted (dot labelled "QS" at 0 Gauss).

Fig 9. Transverse Velocity vs. Spatial Resolution. The RMS horizontal velocity is shown plotted as a function of FWHM of the gaussian used by the correlation tracker for 4 different regions of the Sun. As the magnetic field strength and spatial resolution increase, so does the RMS velocity.

Fig 10. Divergence and Exploding Granules. The divergence of the flow field in quiet sun (fig. 1, red - positive divergence or upflows blue - negative divergence or downflows) with the location of 41 exploding granules superimposed. Exploding granules tend to occur at or near areas of positive divergence.

FIG. 1



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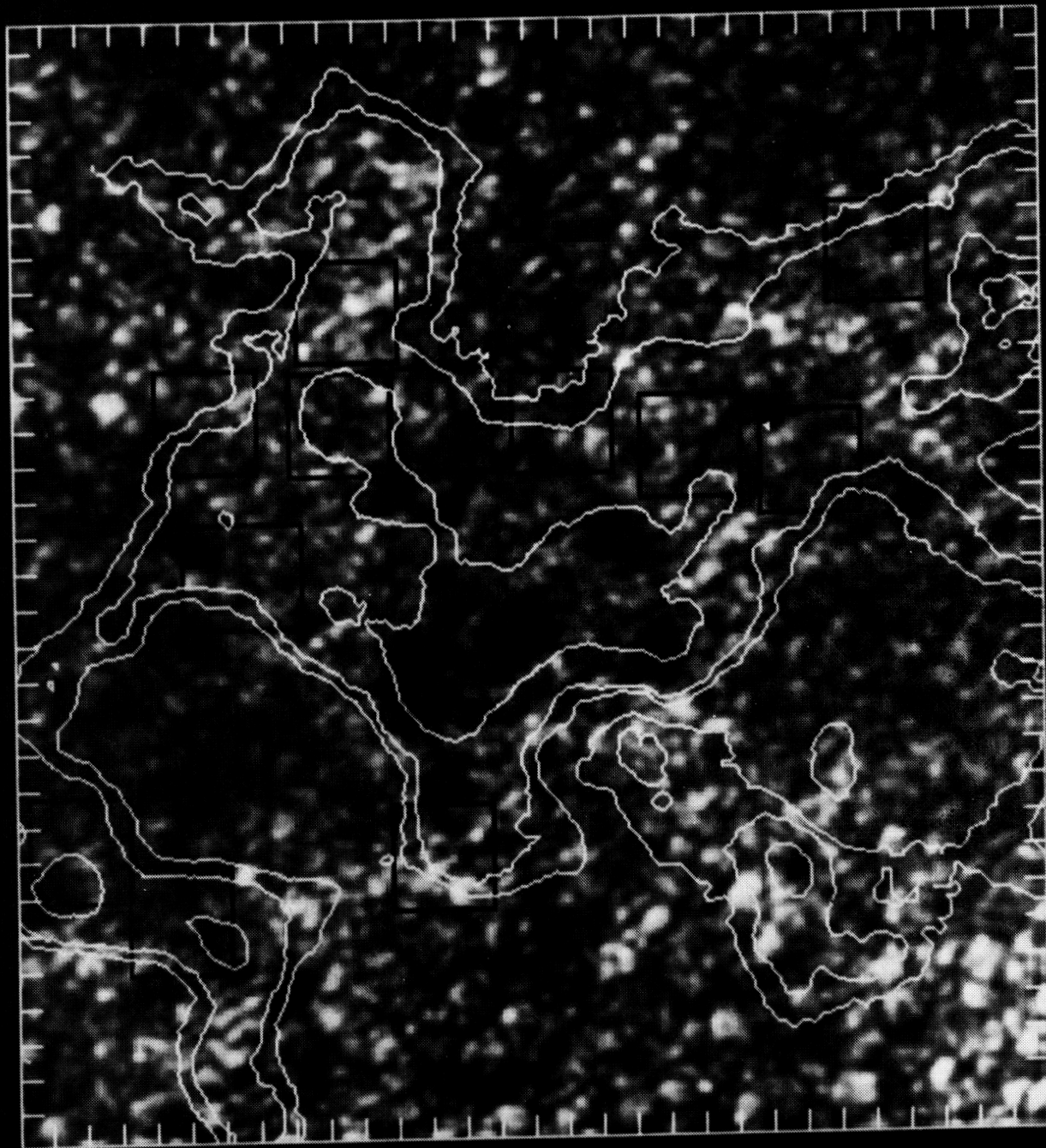


FIG. 2

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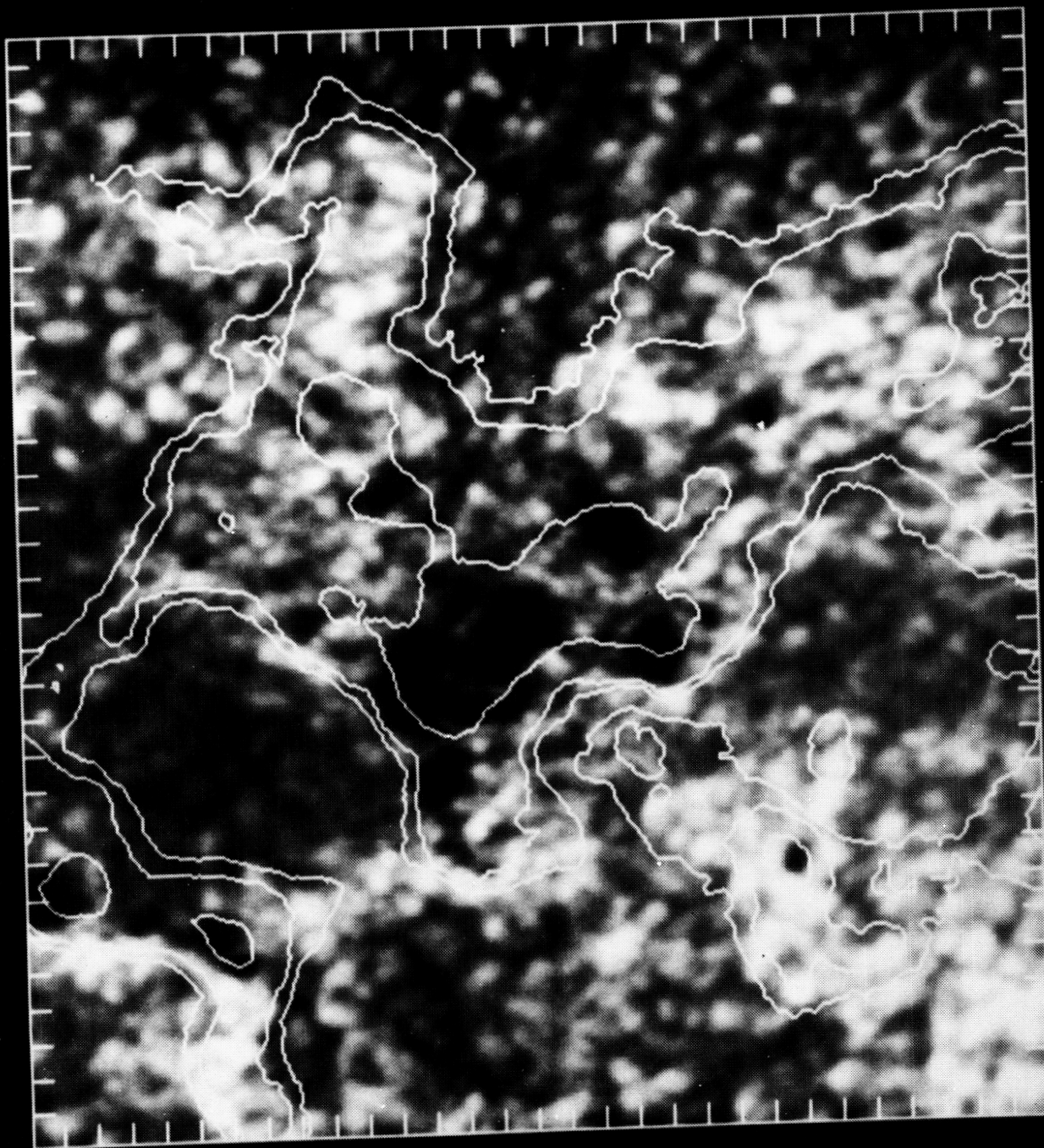


FIG. 3

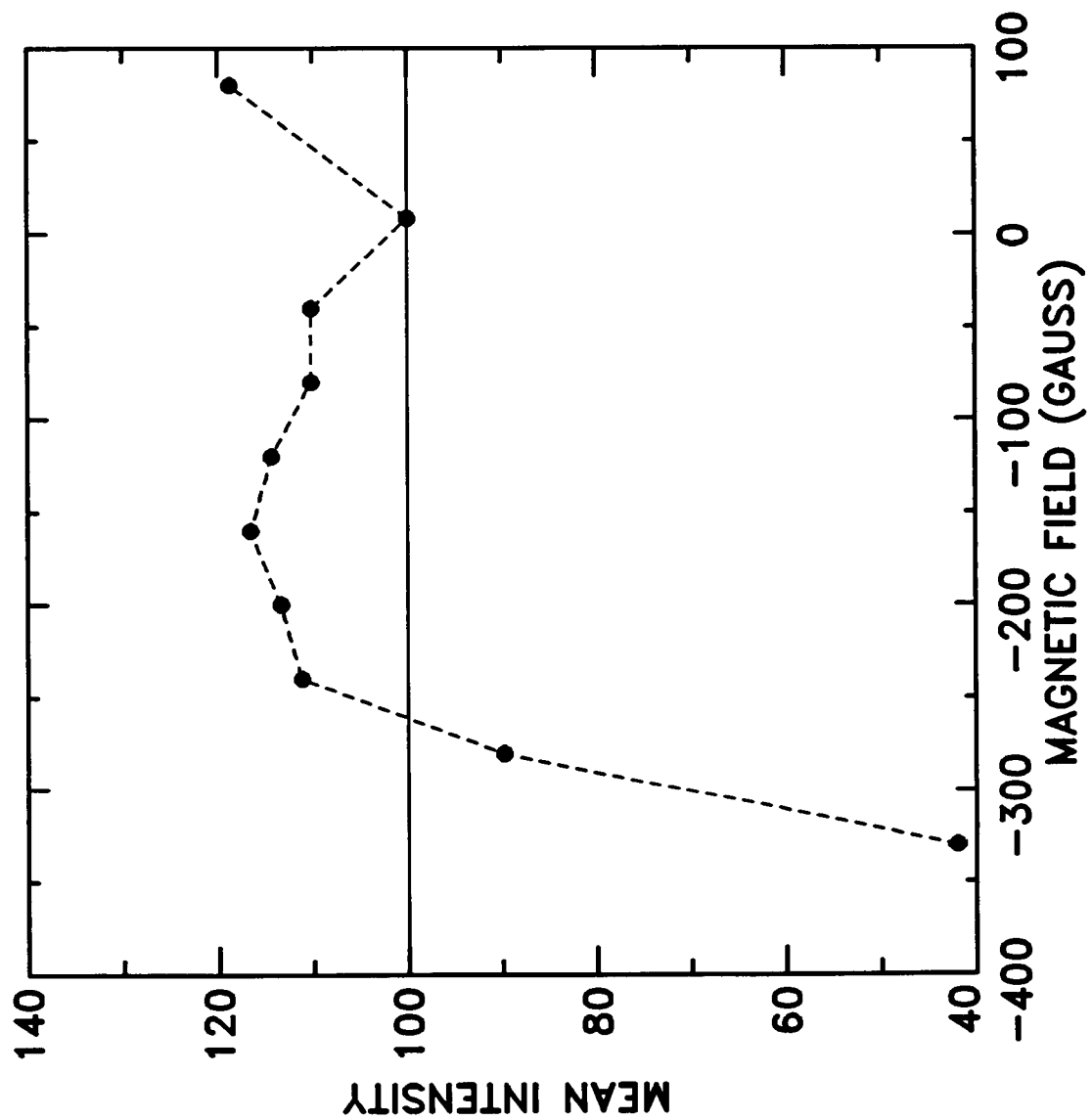


FIG 4

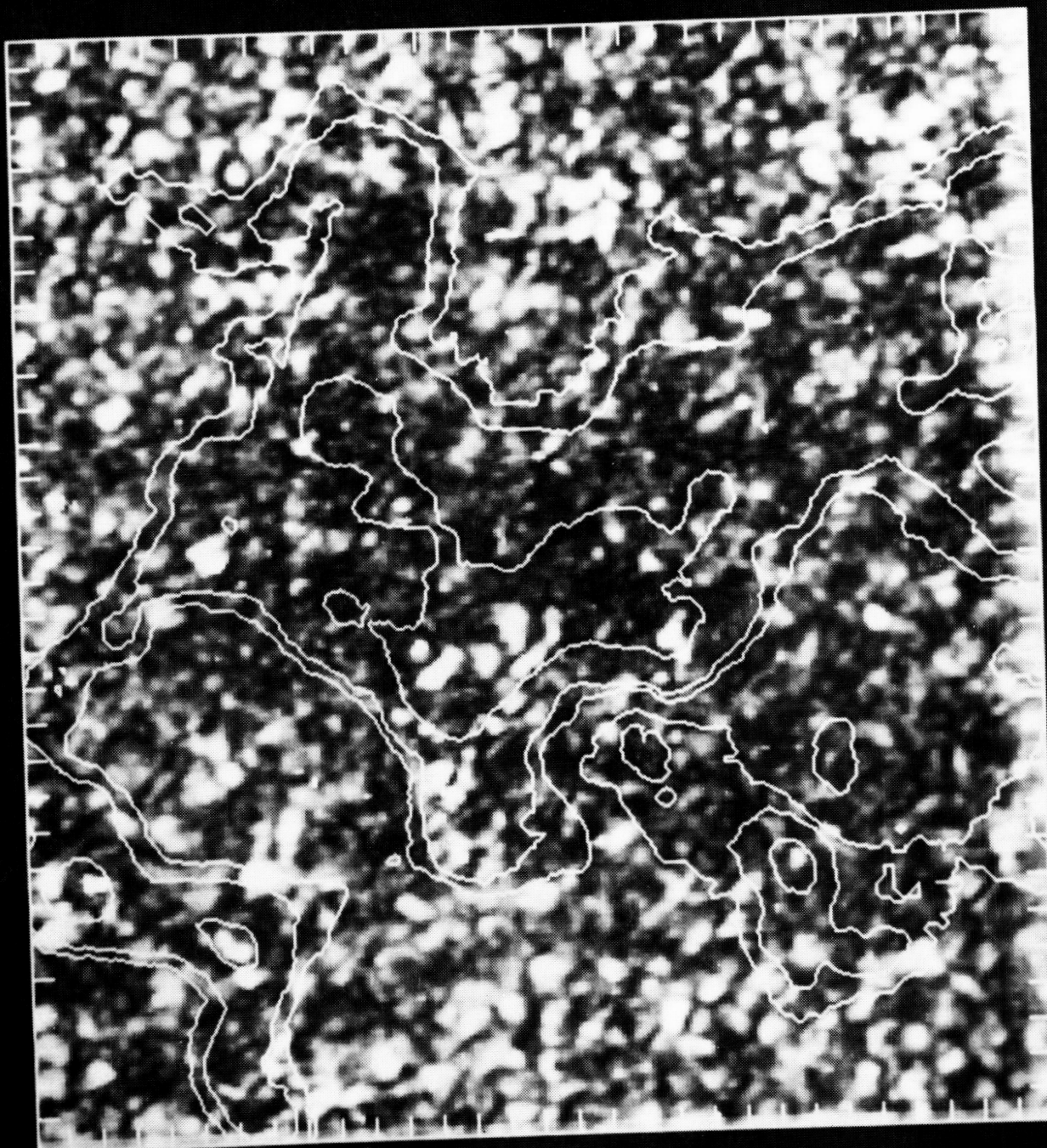
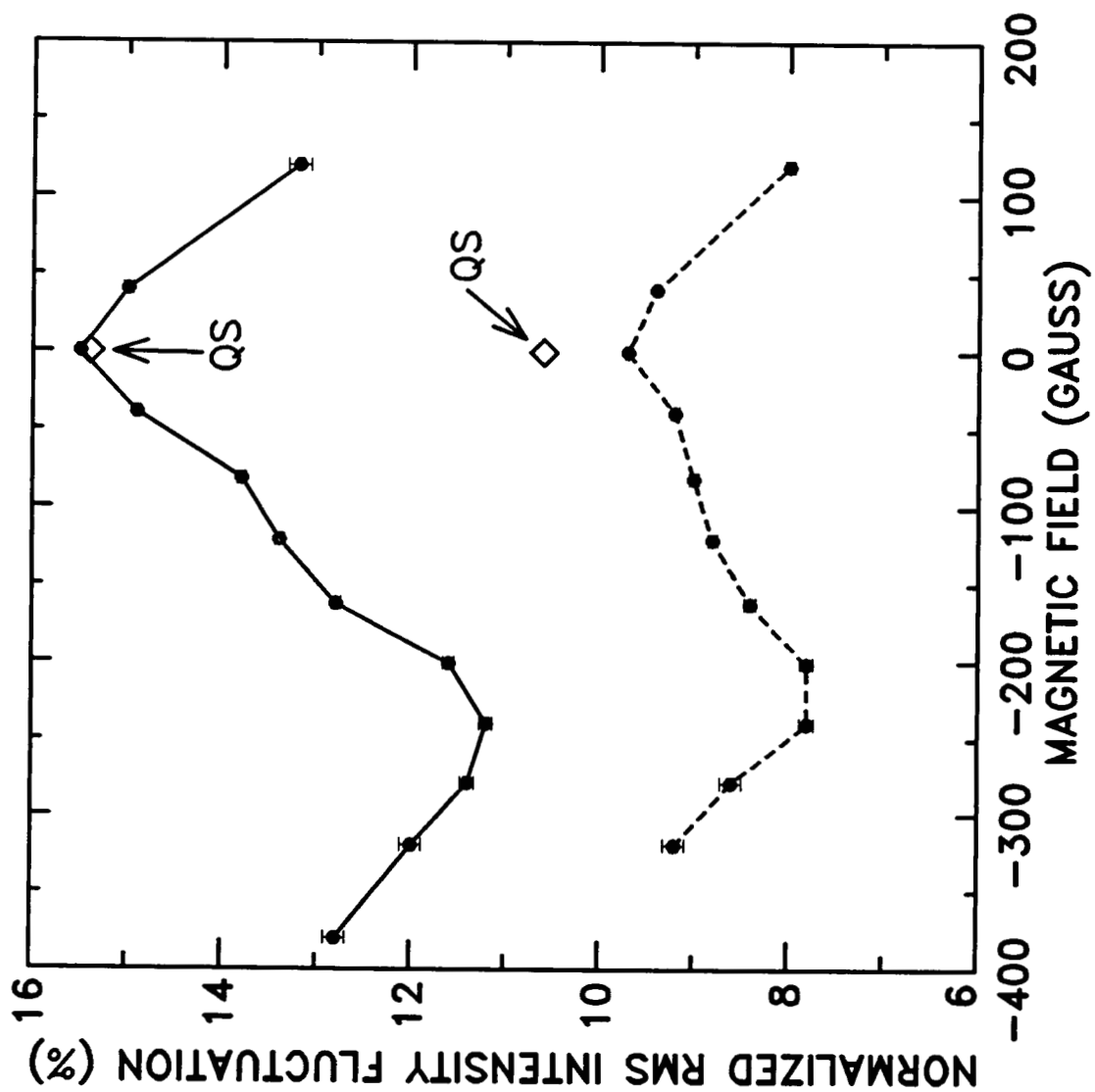
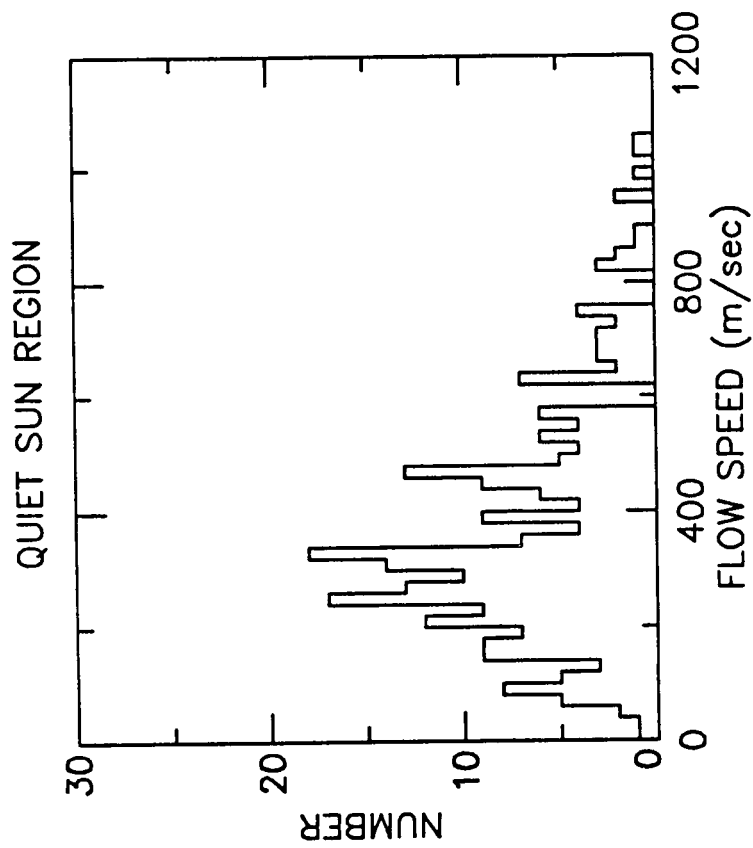
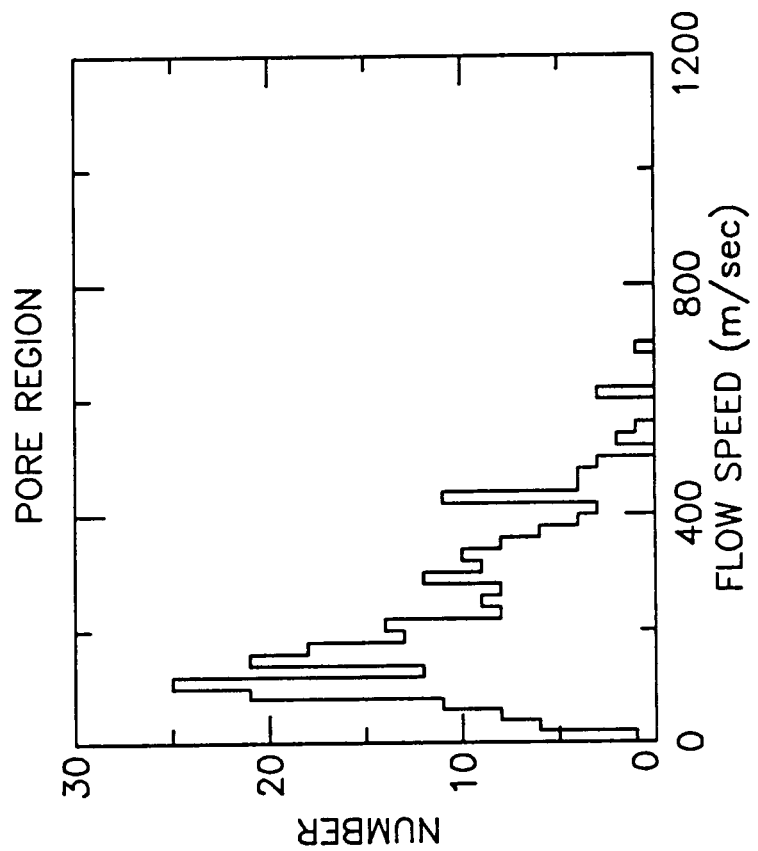


FIG 6





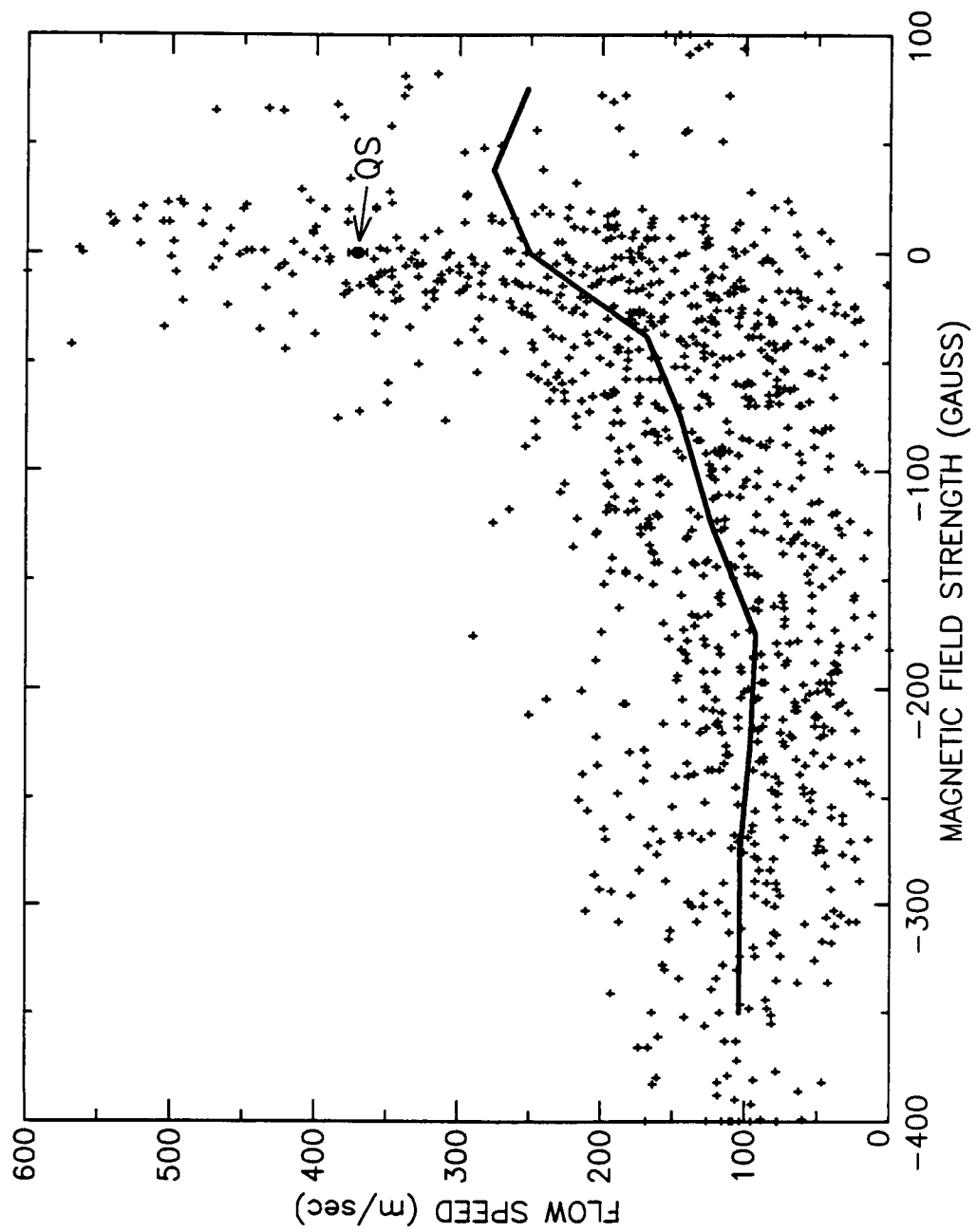


FIG 8

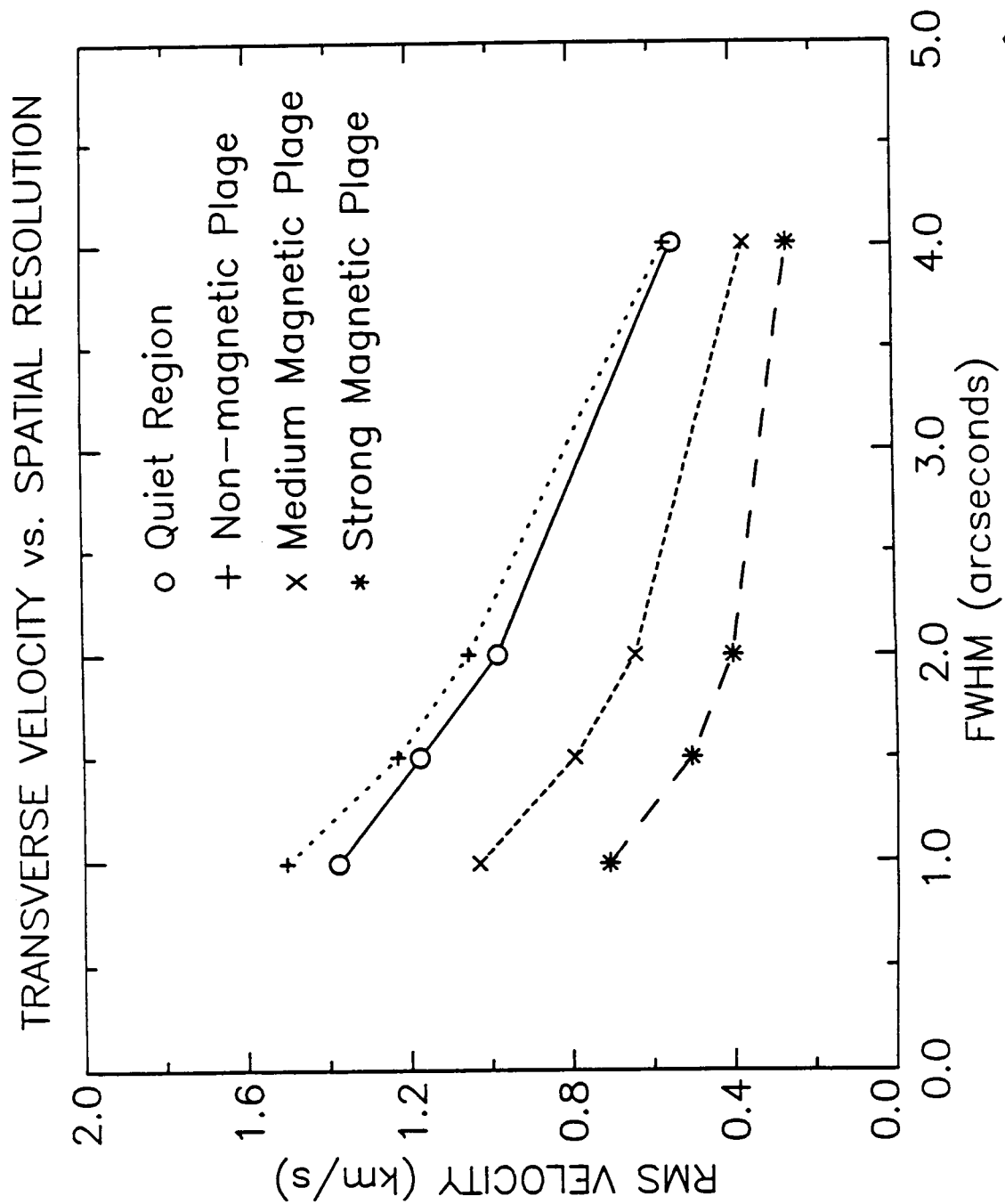


FIG 9

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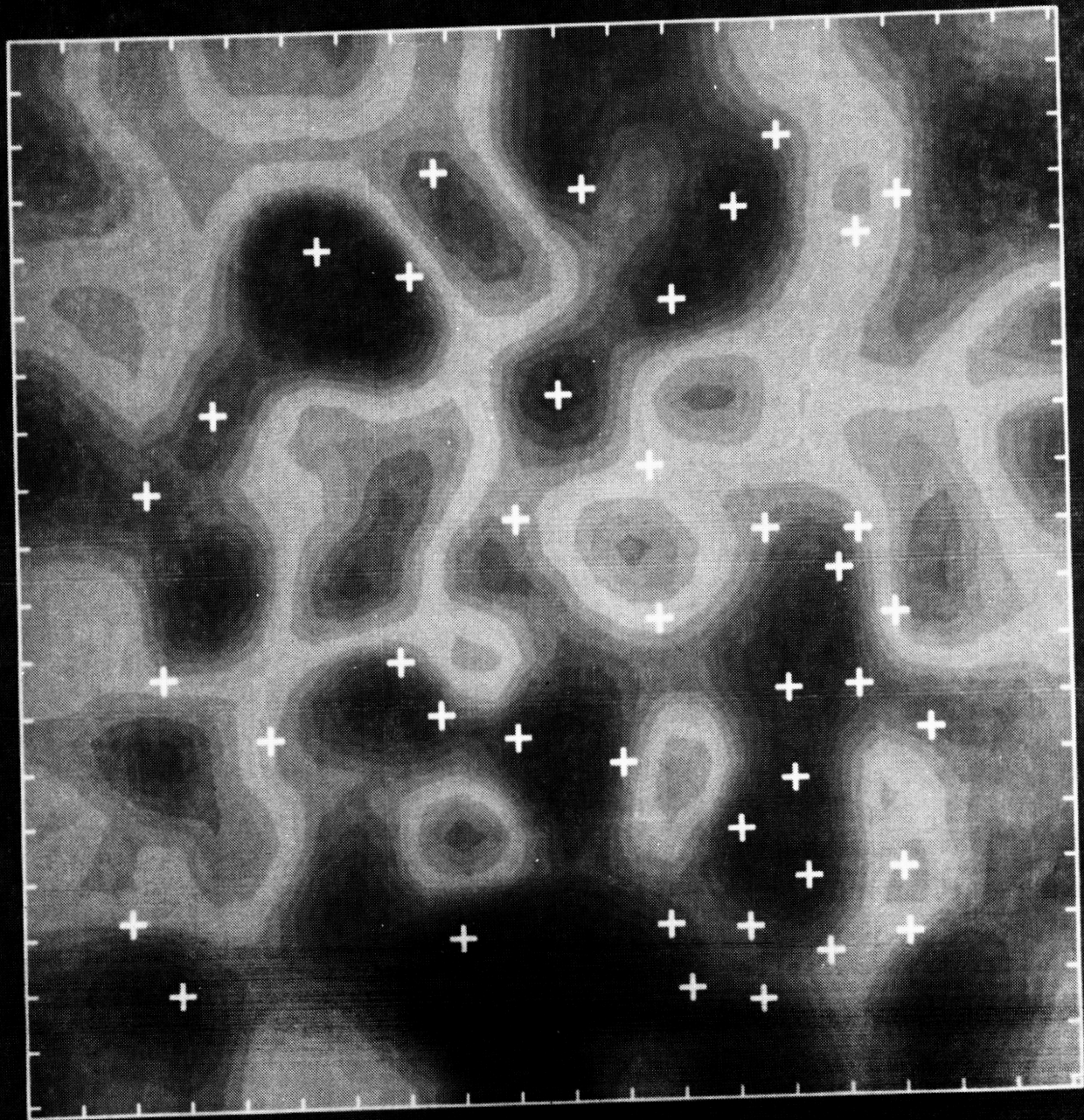


FIG. 10